

**Exercise and Osteoporosis: Methodological and Practical Considerations**

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**Introduction**

Physical activity may have important implications for enhancing bone density prior to the initiation of space flight, for preserving bone density during zero gravity, and for rehabilitating the skeleton upon return to Earth. Nevertheless, the beneficial effects of exercise upon the skeleton have not been proven by controlled trials and no consensus exists regarding the type, duration, and intensity of exercise necessary to make significant alterations to the skeleton. The following sections review our current understanding of exercise and osteoporosis, examine some of the methodological shortcomings of these investigations, and make research recommendations for future clinical trials.

**Cross-sectional Studies: Exercisers versus Comparison Subjects**

The majority of studies that have compared individuals participating in habitual physical activity with less active comparison subjects have found greater bone density in the former [1, 2]. The finding of higher bone density values among athletes does not appear to be site or exercise specific. For example, in two classic studies Jones *et al.* [3] and Huddleston *et al.* [4] observed unilaterally greater bone density in the playing arms of lifetime tennis athletes when compared with their nondominant arms. However, a number of additional studies [5, 6, 7] have found similarly higher levels of peripheral bone density regardless of the type of activity. Athletes also appear to have greater spinal bone density whether engaged in activities that are weight-bearing [8, 9, 10] or nonweight-bearing [10, 11]. Recent studies likewise found greater hip bone density among athletes [10, 12]. While the bulk of these types of studies shows greater levels of bone density in athletes, not all do [2, 13] and their cross-sectional nature suggests that selection bias may be another reasonable explanation for these apparently positive findings.

**Cross-sectional Studies: Fitness Predictors of Bone Density**

In an attempt to explain the variability in bone density seen in normal populations as well as athletes, a number of investigators have examined the predictive ability of objective measures of physical fitness. are some of the variables that have been assessed and related to standard determinations of bone density.

Pocock *et al.* [14] and Chow *et al.* [15] observed that aerobic capacity was an independent predictor of both spine, hip, and total body bone density. In the study by Pocock and colleagues [14], aerobic capacity, in fact, was found to explain a greater amount of the variability in bone density than either age or parameters of body mass. The findings of these first studies led some investigators to conclude that participation in any activity that significantly increases aerobic capacity will have a salubrious effect on bone as well. However, several subsequent studies have failed to confirm these earlier findings. Bevier *et al.* [16] found that aerobic capacity was not correlated with radial or spinal bone density in older women; however, in older men the relationship was significant. A more recent study by Pocock and coworkers [17] showed that

muscular strength had greater predictive value than aerobic capacity at the hip in women over the entire age range.

Block and colleagues [10] did not observe a significant relationship between aerobic capacity and bone density in either the trabecular portion of the spine or the hip in young men engaged in rigorous aerobic or anaerobic physical activity. Lastly, Kirk *et al.* [18] observed a strongly positive ( $r=0.509$ ,  $p<0.03$ ) relationship between aerobic capacity and spinal trabecular bone density in sedentary women and female runners who were premenopausal; this relationship did not hold up among postmenopausal women. One explanation for these equivocal findings is that activity, per se, may have some impact on bone density but the mechanism may not be one where the predominant factor is aerobic capacity. Athletic individuals have generally greater bone density and generally greater aerobic capacity, but whether the two are uniquely related remains uncertain.

Investigations that have examined the role of muscular strength in predicting the variability in bone density have consistently, although not without exception, found that this fitness parameter is an important contributor. Sinaki and colleagues [19], Bevier *et al.* [16], and Pocock *et al.* [17] all observed a moderately strong relationship between bone density at several sites and muscular strength as assessed by varying methods. While Block *et al.* [10] did not find a significant correlation between spinal trabecular bone density and back strength, they did observe a robust relationship between the cross-sectional area of the paraspinal musculature and the density of both the trabecular and integral portions of the thoracolumbar spine.

Several other parameters of physical fitness have likewise been found to be associated with bone density including daily energy expenditure and determinations of body composition. Kanders and colleagues [20] showed a moderately strong correlation ( $r=0.41$ ,  $p<0.005$ ) between average daily energy expenditure as expressed in kilocalories and vertebral integral bone density. Results have been somewhat mixed when body composition studies have been examined as possible predictors of bone density. Pocock *et al.* [17] observed a positive association between body mass index and femoral bone density in addition to it being a strong, independent predictor. However, Stillman and coworkers [21] observed that while females with a history of physical activity had greater bone density, they were significantly leaner.

## Prospective Studies

The limited number of prospective studies of the effects of various types of exercise programs on bone density have yielded conflicting findings [1]. The majority of studies failed to show that exercise of short duration can significantly enhance radial compact bone density [22, 23, 24, 25]; although in several of these studies, the nonexercising group showed significant losses over the study period [25, 24]. Report of a long-term trial by Smith and colleagues [26] found favorable results of a 4-year exercise program on radial bone density in women over a large age range. Additionally, an earlier study by Smith and coworkers [27] reported a significant increase in radial bone density among nursing home residents participating in a 3-year fitness regimen.

Prospective studies examining the benefits of exercise at the spine have been few in number, although several controlled trials are currently underway. Krolner *et al.* [25] observed an insignificant increase in spinal integral bone density among postmenopausal women engaged in a physical fitness program; however, the posttreatment differences between exercisers and less active control subjects was significant. Dalsky and colleagues [28], on the other hand, found a significant rise in spinal integral bone density following 9 months of running exercise in postmenopausal women, but could not identify a significant difference between intervention and control women over this duration.

In a review of the literature, Block *et al.* [1, 2] suggested that the disparate findings from prospective studies may, in part, be due to serious methodological shortcomings. While investigations of prospective design provide the only means of establishing valid relationships between exercise and bone density accretion, good methodological rigor has not been adhered to in most of the clinical trials that have been undertaken. Randomization is the best way to avoid many of the biases that can lead to invalid results. Unfortunately, only one published study has utilized a randomized design [29]; this investigation showed no effect of a generalized walking program on radial bone density among a large population of postmenopausal women. Lack of randomization in all other prospective trials renders their results suspect.

Several additional methodological flaws are evident in prospective investigations of exercise and bone density and may have lead to invalid conclusions. No study accounted for extraneous events and influences that took place between baseline and final bone density measurements (e.g., drug and medication usage, dietary changes, additional fitness programs), no estimations were made of the sample size or power necessary to detect "real" changes in bone density, questionnaire instruments used to categorize subjects lacked appropriate validation, and no attempt was made to identify characteristics of dropouts or to adjust statistically for the significant attrition that occurred in several of the studies.

Certainly the lack of methodological rigor, coupled with the somewhat mixed results from the published prospective trials to date, make it difficult to confidently recommend exercise as an effective agent for building or maintaining bone density. Gains observed after initiating exercise have not been nearly as impressive as those anticipated by extrapolating from the cross-sectional studies of athletes and nonexercisers. Additionally, because no consensus has been reached on the type, duration, or intensity of exercise necessary to make significant bone density gains, no clinical prescription can be currently recommended. Lastly, physiological and practical considerations must be given equal consideration when designing exercise programs. Recent research using animal and *in vitro* models suggests that certain biomechanical actions may have the greatest benefit for the skeleton. However, whether these theories can be translated into practical fitness program remains to be tested. From a public health standpoint, an exercise program that provides only a small benefit to the skeleton but can be adhered to by a large cross-section of the general population has greater ramifications than a very specific regimen, with perhaps potentially large skeletal benefits, that can only be adhered to by a select few.

### **Current Research Priorities and Conclusions**

Exercise strategies have tremendous potential for affecting bone density and reducing the likelihood of osteoporosis over a large age range compared to other possible interventions. For example, fitness programs might be utilized in young adults to enhance the level of peak bone density (i.e., primary prevention). Additionally, either by itself or in combination with some other intervention, exercise may be effective in reducing the rapid loss of bone that occurs with the cessation of ovarian function at the time of menopause (i.e., secondary prevention). Lastly, fitness programs might be used among the elderly population to modify risk factors for falls and fractures without specific increases occurring necessarily in bone density (i.e., tertiary prevention).

Randomized, prospective trials need to be undertaken in a number of different age and sex populations, examining the effects of different types and durations of exercise on bone density and other factors associated with fracture. These rigorously designed studies potentially will rectify the methodological shortcomings inherent in previous prospective trials. We believe immediate research attention should be focused in two distinct areas: enhancement of peak bone density and possible detraining effects on the skeleton. It is thought that the level of peak bone density is a

support this hypothesis. However, Melton *et al.* [30] have projected from population-based data at the Mayo Clinic that any alterations made to bone density among younger adults will have significantly greater effects at reducing the risk of fracture than equivalent changes made among older adults. In fact, their projections would indicate that even therapeutic interventions that have large effects on the skeleton in the elderly will do little to reduce the risk of hip fracture. Regarding the focus on detraining issues, one prospective study [28] suggests that any gains in bone density made as a result of fitness training will be lost following the cessation of exercise. This concept should take a research priority because of its particular relevance to long-term space flight. Controlled trials should be undertaken to explore the specific detraining effects as a function of age, sex, type and duration of exercise, as well as an examination of possible maintenance programs that might be incorporated if bone density can be enhanced preflight.

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## **Section 4**

### **Electrical Stimulation in Exercise Training**

